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**Sheet 2 of the certificate**  
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## Optical storage medium

The invention relates to an optical storage medium for reading and recording information by means of a focused radiation beam having a wavelength  $\lambda$ , said medium comprising:

-a substrate, having a complex refractive index  $\tilde{n}_{s\lambda} = n_{s\lambda} - i \cdot k_{s\lambda}$  at the wavelength  $\lambda$ ,  $n_R$  denoting the real part and  $k_s$  denoting the imaginary part of  $\tilde{n}_{s\lambda}$  including a guide groove with a depth  $g$ , an average width  $w$  and a trackpitch  $p$  and  $w$  in the range of 0.2 to 0.8 times  $p$ ; and

-a stack of layers on the substrate, which stack includes:

-a recording layer of a material having a complex refractive index  $\tilde{n}_{r\lambda} = n_{r\lambda} - i \cdot k_{r\lambda}$  and having a thickness  $d_{RG}$  in the groove portion and a thickness  $d_{RL}$  in the portion between grooves; and

-a reflective layer of a material having a complex refractive index  $\tilde{n}_{m\lambda} = n_{m\lambda} - i \cdot k_{m\lambda}$  and being present between the substrate and the recording layer.

The invention further relates to an optical storage medium for reading and recording information by means of a focused radiation beam having a wavelength  $\lambda$ , said medium comprising:

-a substrate, including a guide groove with a depth  $g$ , an average width  $w$  and a trackpitch  $p$  and  $w$  in the range of 0.2 to 0.8 times  $p$ ; and

-a stack of layers on the substrate, which stack includes:

-a recording layer of a material having a complex refractive index  $\tilde{n}_{r\lambda} = n_{r\lambda} - i \cdot k_{r\lambda}$  and  $k_{r\lambda} < 0.5$  and having a thickness  $d_{RG}$  in the groove portion and a thickness  $d_{RL}$  in the portion between grooves; and

-a reflective layer of a dielectric material and being present proximate the recording layer.

Regarding the market for optical recording, it is clear that the most important and successful format so far is a write-once format, CD-R. Although the take-over in importance by CD-RW has been predicted since a long time, the actual market size of CD-R

media is still at least an order of magnitude larger than for CD-RW. Furthermore the most important parameter for drives is the maximum write speed for R-media, not for RW. Of course, a possible shift of the market to CD-RW is still possible, e.g. because of Mount Rainier standardization for CD-RW. However, the R-format has been proven very attractive due to its 100% compatibility.

Next to the DVD+RW standard recently a new DVD+R standard was developed. The new DVD+R standard gets increasing attention as an important support for DVD+RW. A possible scenario is that the end customers have become so familiar with an optical write-once format that they might accept it more easily than a re-writable format.

An issue for both the R and RW formats is the limited capacity and therefore recording time because only single-stacked media are present (for DVD-Video read only, dual stacked media have a considerable market share). A dual-layer DVD+RW disc is probably feasible. However, it has become clear that a fully compatible disc, i.e. within the reflection, modulation and tracking specification of the dual-layer DVD-ROM, is very difficult to achieve. Without a full compatibility, the success of a dual-layer recordable DVD in the market is questionable.

It is an object of the invention to provide an optical data storage medium of the type mentioned in the opening paragraph having a tracking signal which is compatible with the existing DVD standard for read only disks.

This object is achieved with a an optical storage medium with characteristics which are described hereinafter.

1. Optimum groove depth range for the inverted recording layer of a DVD+R-DL optical disc

#### 1.1 Abstract

A range of groove depths is depicted that allows *m*-groove tracking of the inverted L1 recording stack of a dual-layer dye-based recordable DVD disc.

#### 1.2 Introduction

In known optical storage media the guide groove or pregroove track comprises a spiral groove in the transparent substrate and the recording layer is a thin layer of, for example, an organic dye. A focused laser beam of sufficiently high intensity can produce an optically detectable change in the recording layer. The guide groove extends across the entire

optical storage medium surface. During recording the groove is employed for detecting the radial position of the laser write spot formed on the recording layer by the focused laser beam, relative to a groove, so that the radial position of the write spot can be corrected. As a result of this, less stringent requirements have to be imposed on the drive and guide  
5 mechanism for moving the write beam and the optical storage medium relative to each other, enabling a simpler and cheaper construction to be used for the write apparatus.

The radial position of the laser write spot relative to the groove is detected by means of the so-called "push-pull" or differential method. This method employs two radiation-sensitive detectors arranged in the path of the beam which has been reflected from  
10 the optical storage medium so that the detectors receive radially different portions of the reflected beam. The difference between the output signals of the two detectors contains information about the radial position of the laser spot relative to the groove. If the output signals are equal, the center of the laser spot coincides with the center of the groove or the center between two adjacent grooves. The differential tracking method can be used only if  
15 the depth of the grooves is such that the phase shift between the radiation reflected from a groove and the radiation reflected from the area surrounding the groove is approximately  $(\frac{1}{2} + n)\pi$  where  $n=0$  or an integer number. This phase shift is given by:  $\Delta\phi = -4\pi n g / \lambda$ , in which  $g$  is the groove depth,  $n$  the refractive index of the substrate material and  $\lambda$  the wavelength of the radiation used. Moreover, for an optimum tracking signal the amplitude of  
20 the radiation reflected from the groove must be equal to that of the radiation reflected from the area surrounding the groove.

These requirements are met if the recording layer is a relatively thin layer of equal thickness both inside the grooves and between the grooves as is the case for e.g. the Digital Versatile ReWritable Disk (DVD RW) in which case a thin metal alloy is used which  
25 can be formed by vacuum-deposition or by means of a sputter process.

It has been found that layers of specific dyes are very suitable for use as a recording layer on a pre-grooved record-carrier substrate. Such a dye may be, for example, a phthalocyanine compound, which can be deposited by spincoating a solution of such a compound on the substrate surface. When a layer of dye is applied to a pre-grooved optical  
30 storage medium substrate the grooves are filled partially or completely and the thickness of the layer at the location of the grooves dRG will generally be greater than the thickness dRL between the grooves. The area between the grooves is also called on-land. As a result of this difference in layer thickness, which is equal to the dRG-dRL, an additional phase shift occurs between the radiation reflected from the recording layer at the location of a groove and

radiation reflected from the recording layer in the vicinity of the groove. This additional phase shift gives rise to a differential tracking signal which is different from the case in which  $dRG = dRL$ . A levelling parameter may be defined as:  $L = (dRG - dRL)/g$ . When  $L=1$  the grooves are completely flattened out by the recording layer, that is the groove structure is not present anymore in the surface of the recording layer opposing the substrate. This could happen for very shallow grooves ( $dG \gg g$ ). However, in most practical cases, e.g. Compact Disk Recordable (CD-R) or DVD Recordable (DVD+R) disks, the levelling parameter ranges from 0.2 to 0.5. For instance, for a typical DVD+R, the groove depth is 160 nm, the dye thickness in the groove is 100 nm and the dye thickness on-land is 40 nm:  $L = (100 - 40)/160 = 0.375$ . When the dye is deposited by a different technique such as evaporation the levelling can be nearly zero, i.e. the same thickness of dye on-land and in-groove.

In an organic dye-based recording stack, the recording process is optimal when the dye volume in which the data are recorded is confined within the grooves present on the surface of the substrate. In case of a normal recording stack, i.e. a CD-R or DVD+R disc, the grooved sections that confine the dye are pointing towards the laser's entry surface of the disc. In the case of an inverted stack, the grooves are pointing away from the laser's entry surface; in this case the land sections, which are in between the grooves, are pointing towards the laser's entry surface. Such an inverted stack structure is used for instance for the new Digital Video Recording Recordable (DVR-R) disk, which is also called Blue Ray disk, and the L1- recording layer, L1 denoting the "lowest" recording layer and L0 denoting the "top" recording layer, of a dual-stack recordable DVD disc, as known from non-prepublished European Patent Application 02075226.7, filed by applicants. However, all current optical disk-drives (CD, DVD, DVR) are tuned to track on-groove, meaning tracking and focusing on the portion of the guide groove structure nearest to the plane of incidence of the laser-light beam. For CD and DVD this means tracking and focusing on the bottom of the groove, for the new DVR disk this means tracking and focusing on-land between the grooves. For the L1 layer of a DVD-R dual stack disk and a DVR disk the recording stack is reversed, in which case the reflective layer is present between the recording layer and the substrate and the laser light is incident through a cover layer (in case of DVR) or a spacer layer (in case of DVD+R dual stack). However, when the stack is reversed, as a result of the requirement that the organic dye disks require in-groove recording (away from plane of incidence) the push-pull signal should be reversed. For DVR RW on-groove is still needed. This means that for the DVR system the radial tracking should switch between on-groove for phase-change RW-media and in-groove for organic R-media. The same holds for going from stack L0 to stack

L1 in an DVD-R dual stack medium. From the optical recording drive perspective, this is a very unfavorable situation because extra functionality has to be built into the drive in order to detect which type of layer or which stack level is to be addressed. Older drives do not have this functionality and therefore would not be compatible with the disks which require in-groove recording.

For an inverted stack structure, which as already said is used for instance for DVR-R and the lower-lying layer of a dual-layer recordable DVD disc, see Fig 1.1. However, all current optical disc-drives (CD, DVD, DVR) are tuned to track *on* groove. Therefore, in non-prepublished European Patent Application 02075226.7, filed by applicants, it has been proposed to invert the push-pull of such an inverted stack. This has the advantage that an optical disc-drive that tracks normal stacks *on* groove, will automatically track the inverted stack *in* groove, which, as explained above, improves the quality of recorded data.

Now a specific range of groove depths for which the required inversion of the push-pull signal of a dye-based inverted DVD recording stack (L1) is achieved is identified.

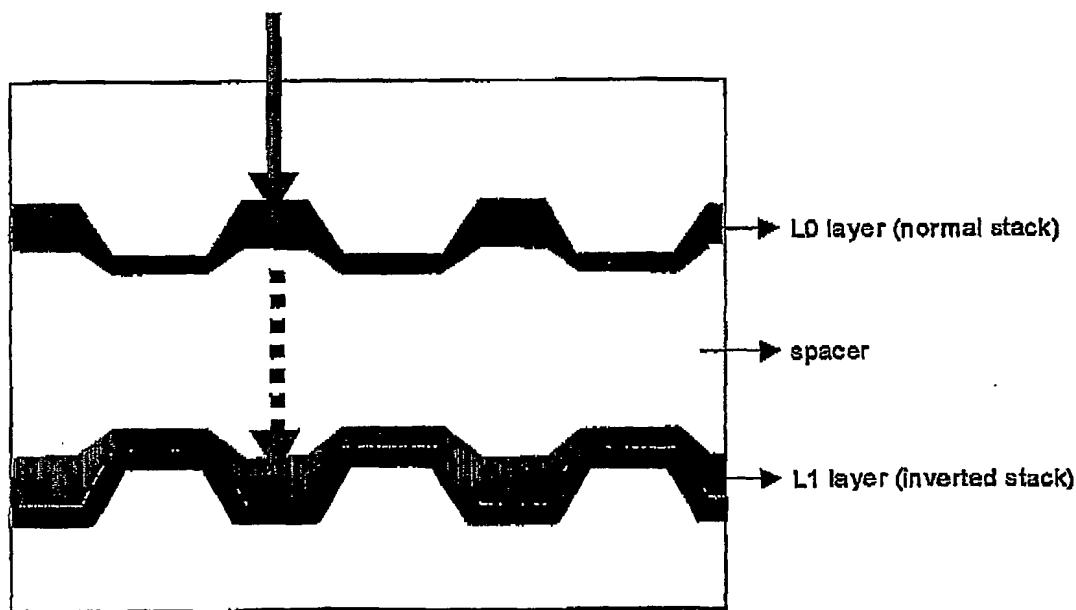


Figure 1.1: Schematic layout of a dual-layer recordable optical disc (e.g. a DVD+R-DL) consisting of two separate pre-grooved substrates, each carrying a recording layer, that are attached to one other by means of the spacer layer. For such a disc the dye-filled grooves in

the L0-layer point towards the laser's entry surface of the disc, while the dye-filled grooves in the L1 layer are pointing away from the laser's (arrow) entry surface, i.e. L1 is an inverted recording stack.

### 5 1.3 Proposal

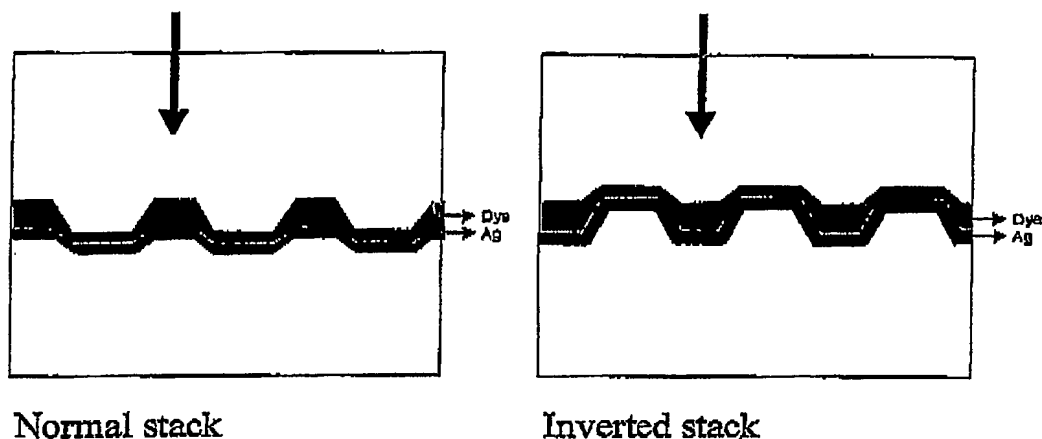


Figure 1.2: Stack structures used in the calculations. On the left hand-side is shown a dye layer on a silver mirror in a normal stack structure. On the right hand-side is shown a dye layer on a silver mirror in an inverted stack structure.

10 In Fig. 1.2 are shown the structures of the normal stack and the inverted stack. The groove depths of these stacks should be such that the normal stack is tracked *on*-groove and the inverted stack is tracked *in*-groove. The recording stack considered in the example-calculations consists of a dye layer and a silver mirror. Commonly, the dyes are applied by means of spin coating. As a result, the thickness of dye in the grooves ( $d_G$ ) is larger than the

15 thickness of dye on the lands ( $d_L$ ); this effect is also illustrated in Fig 1.1 and Fig 1.2. The levelling of the grooves having a depth  $g$  by the spin coated dye layer is quantified by the so-called levelling parameter  $L = (d_G - d_L)/g$ . In case that the dye layer complete flattens out the grooves  $L = 1$ , and this could happen for very shallow grooves ( $d_G \gg g$ ). However, in most practical cases (e.g. CD-R or DVD+R discs) the levelling parameter ranges from 0.2 to 0.5.

20 For instance, for a typical DVD+R, the groove depth is 160 nm, the dye thickness in the groove is 100 nm and the dye thickness on the land is 40 nm:  $L = (100 - 40)/160 = 0.375$ . When the dye is deposited by a different technique such as evaporation the levelling can be nearly zero (same thickness of dye on land and in groove).

25 Fig 1.3 shows the dependence of the push-pull signal for both a normal stack and an inverted stack as a function of groove depth for typical in-groove layer thickness and



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optical constants of the dye for six values of the levelling parameter. Similar results are obtained for different mirror materials and in case of additional protection, interference, deformation, and/or heat-sink layer(s) on top of the dye or in between the dye and the mirror. A different track pitch and/or groove width does influence the amplitude of the push-pull, but

5 leaves the sign of the push-pull unchanged. According to the DVD+R standard, the phase depth of the grooves should not exceed  $90^\circ$ , this means that in the presented calculations the push-pull of the normal stack should be positive. Indeed, for the typical DVD+R parameters mentioned above, the push-pull is found to be positive. Notice that in contrast to the push-pull of a normal stack, the push-pull of the inverted stack always start with a negative sign for

10 increasing groove depths; this is a natural consequence of the inverted stack structure. For  $L = 0$ , the push-pull of the inverted stack has even always the opposite sign of the push-pull of the normal stack.

8  
95 nm dye,  $n=2.3$   $k=0.05$ , on Ag

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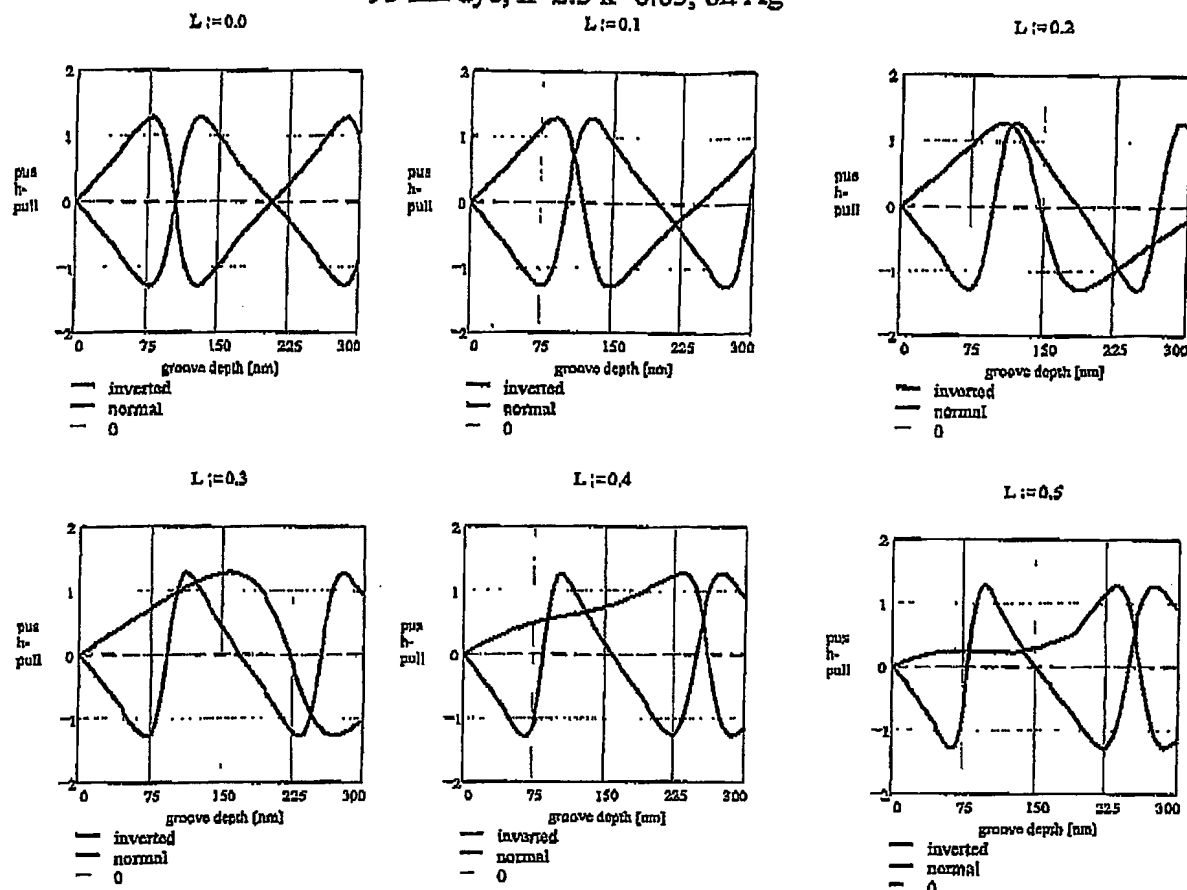


Figure 1.3: Push-pull for a normal stack (line starting with positive slope) and an inverted stack (line starting with positive slope) as a function of groove depth for six values of the levelling parameter. The thickness of the dye is 95 nm in the grooves and  $95-L \cdot g$  nanometer on the lands. The optical constants of the dye are  $n = 2.3$  and  $k = 0.05$ . A thick silver mirror is behind the dye. The laser wavelength is 655 nm, the objective lens numerical aperture is 0.65, the track pitch is 740 nm, the groove width is 370 nm.

#### 1.4 Claimed ranges

In Fig 1.4 the push-pull dependence on groove depth of a number of dye/Ag inverted stacks with different dye thickness, levelling, and dye's optical parameters is shown. For this broad range of (realistic) dye parameters, the push-pull is positive in a groove depth range that is given by:

$$75 \text{ nm} < g < 200 \text{ nm}$$

(1)

Fig 1.5 shows parameter ranges where the push-pull of an inverted stack has the required sign (blue area). The calculations have been performed for typical ranges of the dye's refractive index ( $n=2.2$  to  $n=2.6$ ) for typical in-groove dye thickness ( $d_G=75$  nm to  $d_G=115$  nm) and for typical levelling parameter range ( $L=0.2$  to  $L=0.5$ ). From this it is found

5 that an even more preferred groove depth range for the inverted stacks is given by

$$90 \text{ nm} < g < 170 \text{ nm} \quad (2)$$

According to the DVD+R(W) standard the push-pull of the unwritten disc

10 should be in the range 0.3 to 0.6. Therefore, an even more preferred groove depth range for the inverted stack is

$$100 \text{ nm} < g < 150 \text{ nm} \quad (3)$$

15 Fig 1.6 depicts the preferred range of groove depth for an inverted stack as a function of the thickness of the dye layer in groove. With all values in nanometers, the preferred groove depth range for the inverted stack as a function of in-groove dye thickness becomes:

$$20 \quad 0.50 \cdot d_G + 42 < g < 0.88 \cdot d_G + 75 \quad (4)$$

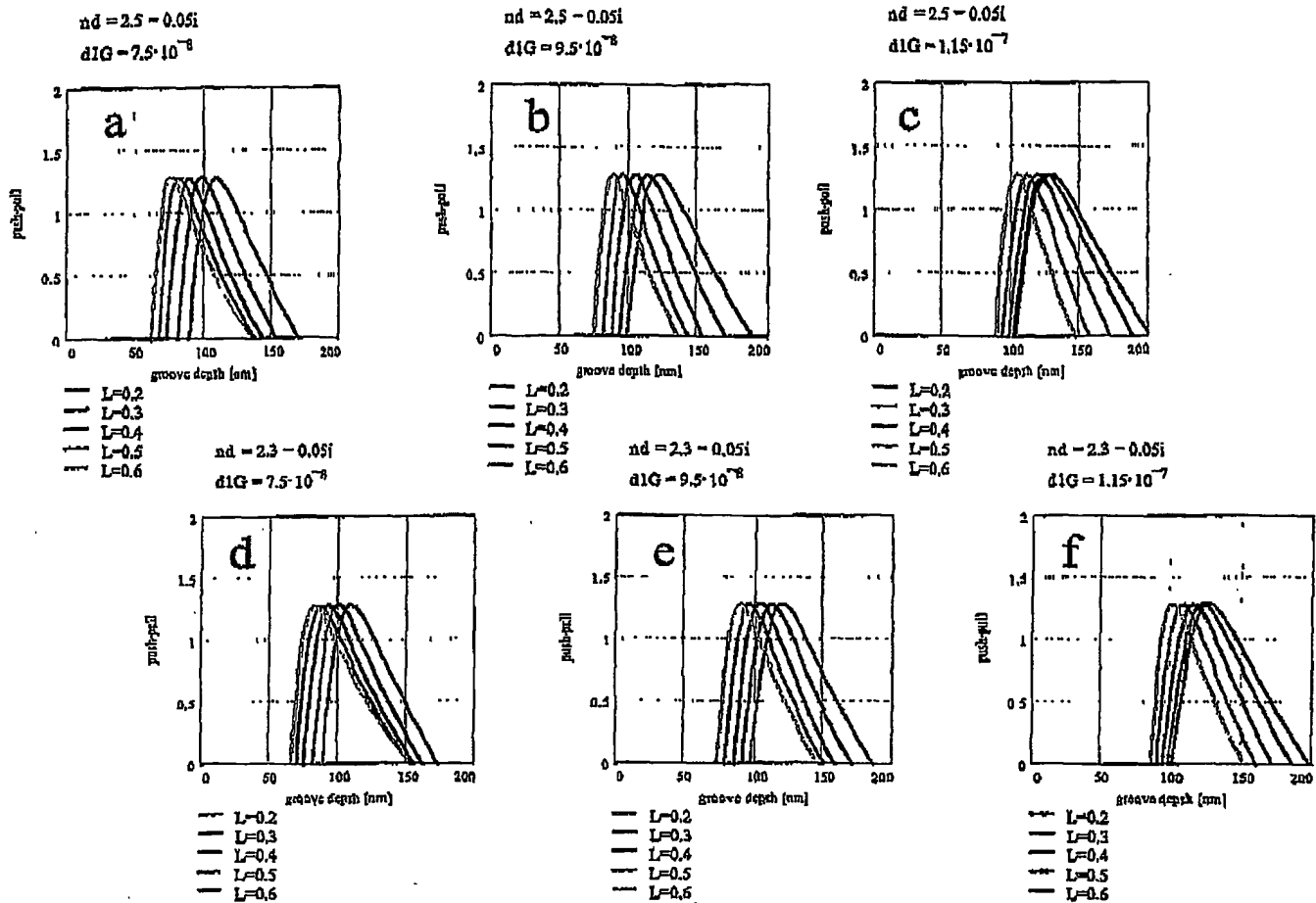
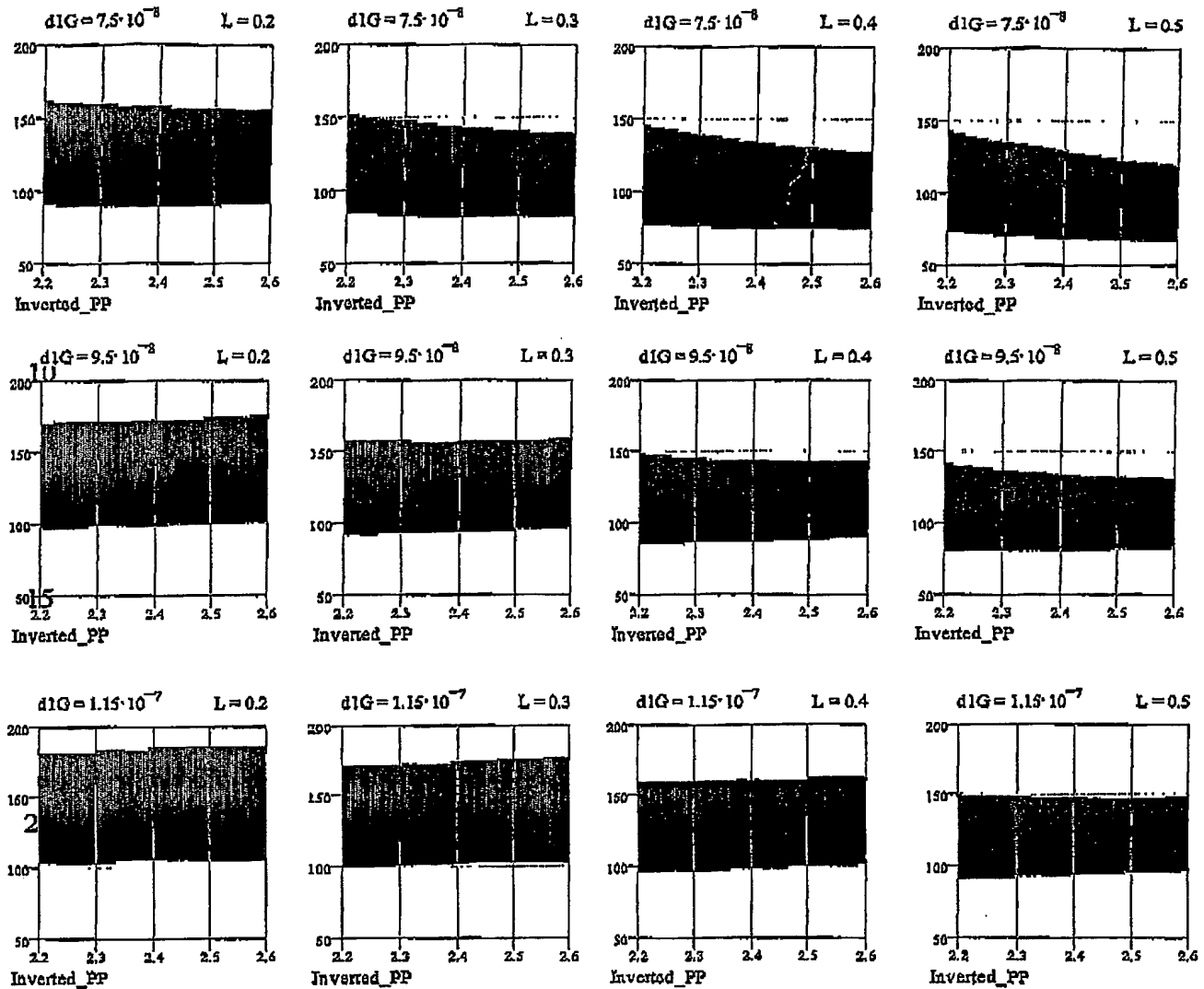


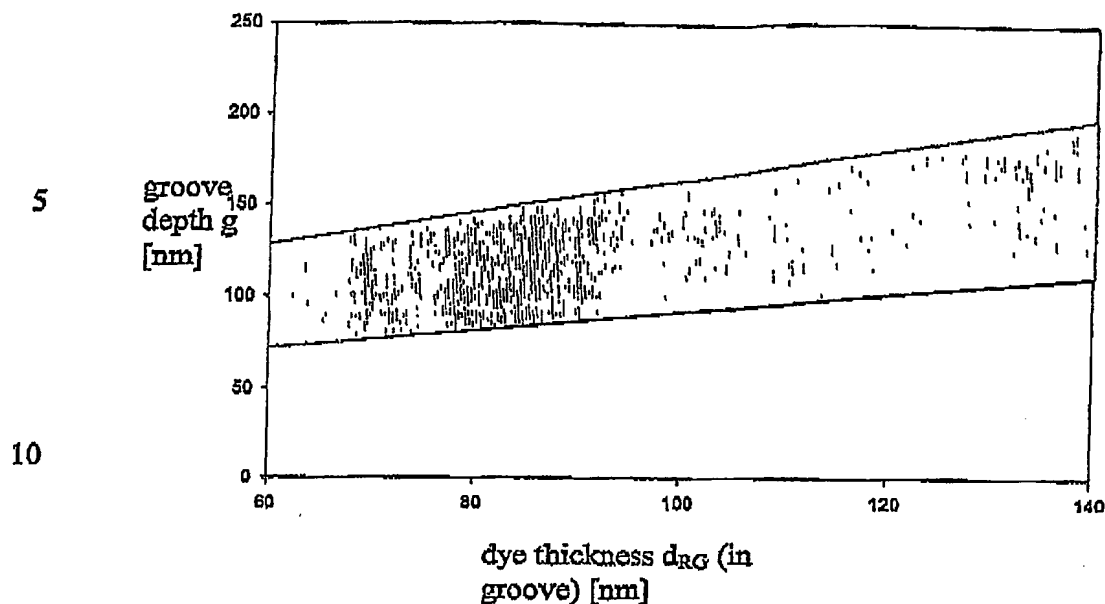
Figure 1.4: Push-pull as a function of groove depth and levelling for inverted stacks consisting of a dye layer on top of a silver mirror. The lowest L-value 0.2 corresponds to the curve most right, the highest L-value 0.6 corresponds to the curve most left. (a)  $n = 2.5$ ,  $k = 0.05$ ,  $d_G = 75$  nm, (b)  $n = 2.5$ ,  $k = 0.05$ ,  $d_G = 95$  nm, (c)  $n = 2.5$ ,  $k = 0.05$ ,  $d_G = 115$  nm, (d)  $n = 2.3$ ,  $k = 0.05$ ,  $d_G = 75$  nm, (e)  $n = 2.3$ ,  $k = 0.05$ ,  $d_G = 95$  nm, (f)  $n = 2.3$ ,  $k = 0.05$ ,  $d_G = 115$  nm.



25

Figure 1.5: Range of inverted push-pull for DVD-type inverted recording layer (dye on Ag) as a function of the dye's refractive index (horizontal axes) and the groove depth (vertical axes) for three values of dye thickness in the grooves (75 nm, 95 nm, 115 nm) and four values of levelling (0.2, 0.3, 0.4, 0.5). The blue area indicates the parameter range for which the push-pull signal is inverted (i.e. positive in the present calculations). The value  $d1G$  above each plot denotes the dye thickness (in groove) in meters and the value  $L$  indicates the levelling.

30

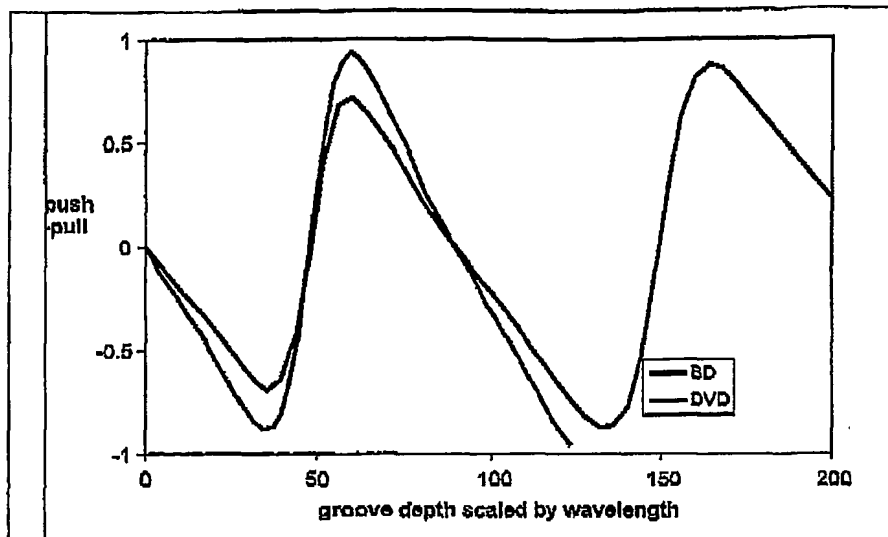


15 Figure 1.6: Preferred groove depth range (shaded area) for an inverted recordable DVD-type stack as a function of the dye thickness in the groove.

#### 1.5 groove depth scaling with $\lambda$

20 All calculations are for dye on metal mirror. For dye on dielectric mirror other results are possible (see chapter 2 and 3).

When the stack design is scaled to  $\lambda$ , the push-pull as function of  $\text{groove depth}/\lambda$  is substantially coinciding (see Fig 1.7). The Figure above has been calculated for BD (Blue-ray Disc, formerly called DVR) and DVD conditions wherein the dye layer thickness as been scaled together with  $\lambda$  and all optical constants have been kept the same.



5 Figure 1.7 BD  $\lambda = 405$  nm (lowest amplitude) versus DVD  $\lambda = 655$  nm

The scaling to  $\lambda$  does not take into account the change of optical constants of the metal mirror layer at different  $\lambda$ 's. E.g for silver the  $k$  changes from  $\sim 4$  at 655 nm to 2 at 405 nm. This has influence on the phase of the reflected light and thus the push-pull signal, see Fig. 1.8 below. The shift however is not very large: about +10 tot +20 nm for  $k = 5 \rightarrow 1$ .

The groove depth can be scaled with  $\lambda$  and will still be fairly accurate at e.g. 405 nm:

$$0.12\lambda < g < 0.28\lambda$$

As function of the dye-thickness at 405 nm the following is valid:

15  $0.75 \cdot dG + 12 < g < dG + 55$

When there is no leveling ( $L=0$  e.g. Rewritable disk) the condition for reversal can be reached when:

$$0.25\lambda < g < 0.50\lambda$$

20 These are deeper grooves because the leveling (thickness difference between land and groove) helps to cause an extra phase-difference on top of the phase difference induced by only the groove depth.

For rewritable disks sign reversal is not desired because in-groove tracking is not desired.

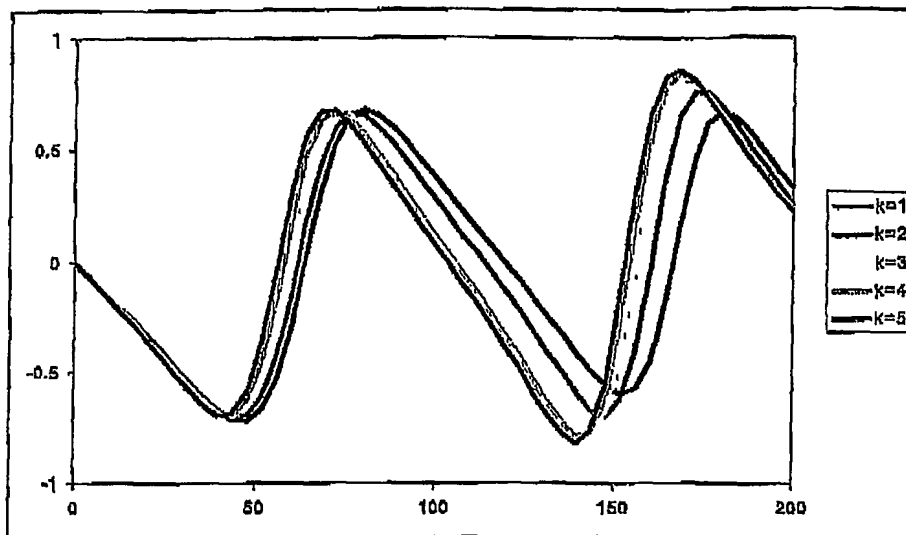


Fig. 1.8 Influence of k of mirror

5

## 1.6 Calculation of Push-Pull signal

Now, the scalar diffraction calculations of the Central Aperture (CA), Radial Contrast (RC), and Push-Pull (PP) signals are outlined, following [1]. As outlined for instance in [2] the complex amplitude-reflection coefficients from the lands  $r_L$  and grooves  $r_G$  can be obtained in a straightforward manner. In the present work, the dye's thickness on land  $d_{d,L}$  is taken dependent on that in the groove  $d_{d,G}$  via the levelling parameter  $L$  and groove depth  $g$ , so we obtain:

$$\begin{aligned} d_{d,L} &= d_{d,G} - L \cdot g \\ d_{d,G} &= (1 - L) \cdot g \end{aligned} \quad (A1)$$

15 Only the 0<sup>th</sup> and 1<sup>st</sup> order diffracted amplitudes are taken into account:

$$A_0 = \left[ \left( 1 - \frac{w}{p} \right) r_L + \frac{w}{p} r_G \right] \quad (A2)$$

$$A_{\pm 1} = [r_G - r_L] \frac{\sin(\pi w / p)}{\pi} \exp\left(\mp 2\pi i \frac{u}{p}\right) \quad (A3)$$



where  $u$  is a measure for the grating's lateral displacement. On the (unit circle) detector, the 0<sup>th</sup> and 1<sup>st</sup> diffracted orders are shifted by a distance  $\Delta x = \lambda/(NA \cdot p)$  with respect to each other; their overlap is expressed by the modulation transfer function  $MTF$ :

$$MTF = \left[ \frac{2}{\pi} \arccos\left(\frac{\Delta x}{2}\right) - \frac{\Delta x}{\pi} \sqrt{1 - \frac{\Delta x^2}{4}} \right] \quad (A4)$$

- 5 For a split detector, the signals  $I_R$  and  $I_L$  on the right and left halves respectively are:

$$I_{R,L} = \left(\frac{1}{2} - MTF\right) |A_0|^2 + MTF |A_0 + A_{\pm 1}|^2 \quad (A5)$$

The signals in the CA- and PP-channel are defined as:

$$CA = I_R + I_L = |A_0|^2 + 2MTF |A_1|^2 + 4MTF |A_0| \cdot |A_1| \cos(\Psi) \cos(2\pi u / p) \quad (A6)$$

$$PP = I_R - I_L = 4MTF |A_0| \cdot |A_1| \sin(\Psi) \sin(2\pi u / p) \quad (A7)$$

- 10 where  $\Psi$  is defined as the phase difference between the zeroth and first diffracted order:

$$\Psi = \arg(A_0) - \arg(A_1) \quad (A8)$$

Now, CA, RC, and (normalized) PP are obtained as follows:

$$CA = CA(u = 0.25p) \quad (A9)$$

$$RC = CA(u = 0.00p) - CA(u = 0.50p) \quad (A10)$$

- 15  $PP = [PP(u = 0.25p) - PP(u = 0.75p)]/CA \quad (A11)$

[1] G. Bouwhuis, J. Braat, A. Huijser, J. Pasman, G. van Rosmalen, and K. Schouhamer Immink, *Principles of Optical Disc Systems*, Adam Hilger Ltd, Bristol (1985).  
M. Born and E. Wolf, *Principles of Optics*, 7<sup>th</sup> Ed., Cambridge University Press, Cambridge  
20 (1999).

[2] R.T.A calculation of a multi-layer stack,  $i^{\text{th}}$  layer has thickness  $d_i$  and complex refractive index  $n_i$ .

25

Fresnel's equations for perpendicular incidence:

Phase differences:

$$m_j := \frac{n_{j+1}}{n_j}$$

$$\phi(vn, vd) := \overline{\left( \frac{2 \cdot \pi}{\lambda} \cdot vn \cdot vd \right)}$$

$$R := \overline{\left( \frac{m-1}{m+1} \right)}$$

$$D := \overline{\left( \frac{2}{m+1} \right)}$$

Boundary & propagation matrix:

$$5 \quad M(i, vn, vd) := \begin{pmatrix} \exp(-i \cdot \phi(vn, vd)_i) & R_i \cdot \exp(i \cdot \phi(vn, vd)_i) \\ R_i \cdot \exp(-i \cdot \phi(vn, vd)_i) & \exp(i \cdot \phi(vn, vd)_i) \end{pmatrix} \cdot \frac{1}{D_i}$$

$$M_{tot}(N, vn, vd) := \prod_{teller=0}^N M(N - teller, vn, vd)$$

Reflection, transmission and absorption of the total stack:

$$r(N, vn, vd) := - \frac{M_{tot}(N, vn, vd)_{1,0}}{M_{tot}(N, vn, vd)_{1,1}}$$

$$R(N, vn, vd) := (|r(N, vn, vd)|)^2$$

$$10 \quad \phi_r(N, vn, vd) := \arg(r(N, vn, vd))$$

$$t(N, vn, vd) := M_{tot}(N, vn, vd)_{0,0} - \frac{M_{tot}(N, vn, vd)_{0,1} \cdot M_{tot}(N, vn, vd)_{1,0}}{M_{tot}(N, vn, vd)_{1,1}}$$

$$T(N, vn, vd) := (|t(N, vn, vd)|)^2 \frac{\operatorname{Re}(vn_{N+1})}{\operatorname{Re}(vn_0)}$$

$$\phi_t(N, vn, vd) := \arg(t(N, vn, vd))$$

$$A(N, vn, vd) := 1 - R(N, vn, vd) - T(N, vn, vd)$$

15

It is another object of the invention to provide an optical data storage medium of the type mentioned in the second paragraph of this document having a tracking signal which is sufficiently large to be compatible with the existing DVD standard for read only disks.

20

This object is achieved with a an optical storage medium with characteristics which are described hereinafter.

2. Optimum groove depth for a transparent DVD-type recording stack having a dielectric mirror

2.2 Abstract

A range of groove depths is depicted that results in a finite push-pull signal, having the correct sign, in the case of a highly transparent optical recording stack in which a dielectric mirror is used.

## 5 2.3 State of the art

To be able to track an empty recordable optical disc (either single-layer, dual-layer, or multi-layer), so-called pre-grooves are present on the substrate on which the optical recording stack is deposited. The pre-grooves result in a phase-difference between light reflected from the grooves and light reflected from the portion in between the grooves (lands). As a  
10 consequence of the different complex reflection amplitudes on land and groove, the incoming laser-light gets diffracted. When detected properly, the interference between the  $\pm 1^{\text{st}}$  and  $0^{\text{th}}$  diffracted orders of the reflected light results in the so-called push-pull signal which can be used by an optical tracking system to keep the laser-light on the pre-grooves. In order for an optical drive to track properly on an empty disc, it is essential that the push-pull signal has  
15 both the correct sign and a finite value. The required values are usually specified in the standard of the concerning optical disc. In general, both the sign and amplitude of the push-pull signal are to a large extent governed by the phase difference between light reflected from land and groove. Therefore, as this phase-difference is mainly governed by the physical depth of the grooves, the groove-depth is the most important parameter that is used to tune the  
20 push-pull properties of a recordable optical disc.

## 2.4 Problem

In a dual-layer recordable optical disc (e.g. DVD+R-DL as described in non-prepublished European Patent Application 02075226.7, filed by applicants) the upper recording layer L0 should be transparent in order to be able to access the lower lying L1 layer through the L0  
25 layer. One possibility to obtain a transparent optical recording stack, is to replace the metal mirror that is used in conventional single layer recordable optical discs by a dielectric mirror. An additional effect of the use of a dielectric mirror is that the phase of the reflected light becomes different compared to the case of light reflected from a conventional metallic mirror. As shown in Fig 2.1 the push-pull in case of a metallic or a dielectric mirror is  
30 markedly different. Even more important, for the typical groove depth of 170 nm used in single-layer DVD+R with metallic mirror, the push-pull in the case of dye-on-dielectric stack is nearly zero: tracking on such a disc is impossible.

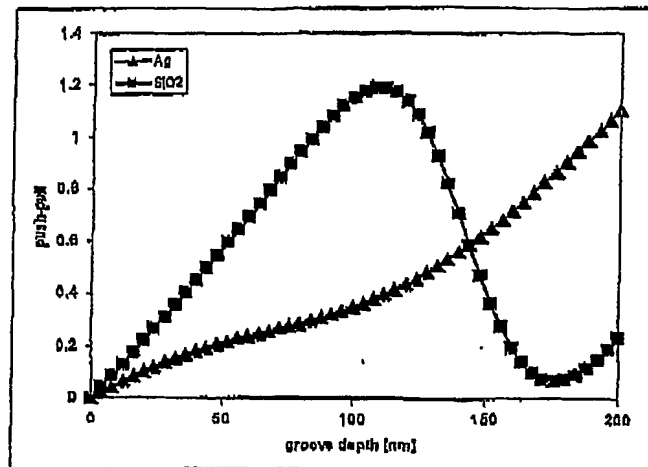


Figure 2.1: Push-pull of dye on a metallic (Ag) mirror and on a dielectric (SiO<sub>2</sub>) mirror versus groove depth. Dye thickness in groove is 80 nm, levelling is 0.4, and dye's refractive index is 2.3.

## 5 Solution

The problem outlined above can be solved by using a different range of groove depths in the case of a dielectric mirror compared to conventional discs having a metallic mirror; specific groove depth ranges will be given below. The advantage of this solution is that radial tracking on such a disc having a stack with a dielectric mirror becomes possible.

10 In Fig 2.2 the push-pull as a function of groove depth is compared for the case of dye-only and dye-on-dielectric stacks. For these stack types, when using the same parameters of dye (thickness, levelling, refractive index), the dependence of the push-pull on groove depth is comparable (extrema, and zero-crossings occur near same groove depth values).

15 Fig. 2.3 shows the push-pull calculated for dye-only stacks as a function of groove depth in a range of realistic parameters: refractive index dye  $n_{\text{dye}} = 2.3 - 2.5$ , levelling dye  $L = 0.2 - 0.5$ , groove width  $w = 300 - 440$  nm. The in-groove dye thickness is  $\lambda/4n_{\text{dye}}$ , i.e. tuned to optimum reflection at the groove. Remarkably, the groove depth range in which the push-pull is finite and of correct sign is hardly dependent on these parameters. From Fig  
20 2.3 it is found that in a groove depth ( $g$ ) range given by

$$g < 125 \text{ nm}$$

(1)

the push-pull of the dielectric-mirror stacks (dye-only and dye+dielectric combination) is finite and of correct sign. The preferred groove-depth range for the dielectric-mirror stacks falls completely out of the range used for metallic-mirror stacks (150 – 180 nm groove depth).

Furthermore, it is important that small variations in groove dimension, inevitable in the fabrication process, do not lead to too strong push-pull variations on the disc. Since Fig. 2.3 shows that in the range 100 nm – 125 nm the push-pull depends very strongly on groove depth, an even more preferable range of groove depth for a dielectric-mirror recordable DVD-type stack is

$$g < 100 \text{ nm}$$

(2)

Finally, as for very shallow grooves the push-pull becomes zero again, the most preferable range of groove depth for a dielectric-mirror recordable DVD-type stack is given by

$$50 \text{ nm} < g < 100 \text{ nm}$$

(3)

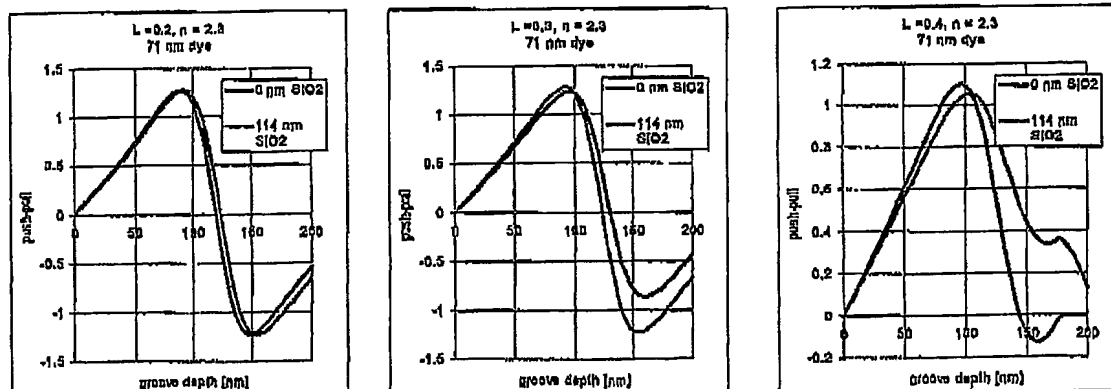
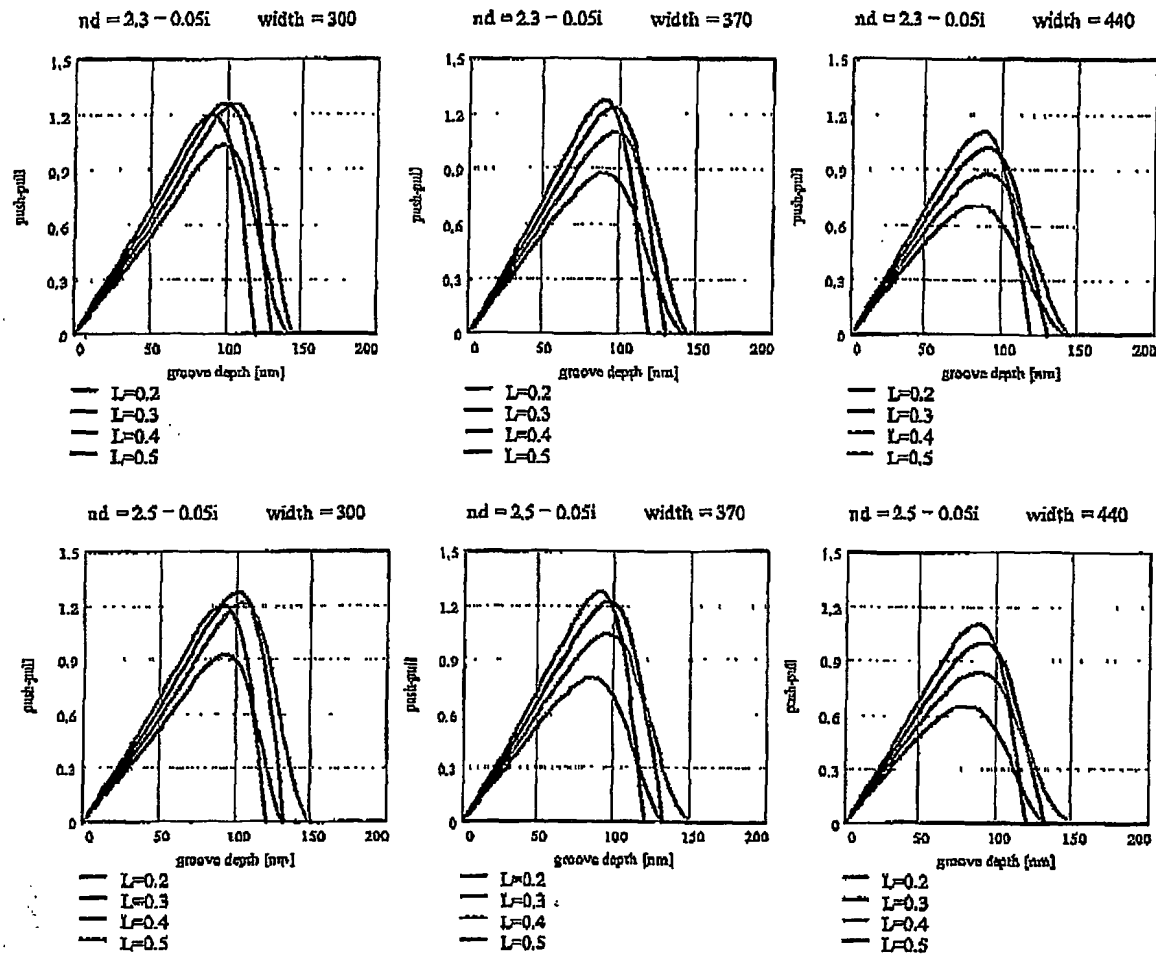


Figure 2.2: Comparison of push-pull from dye-only stack and dye-on-dielectric stack as a function of groove depth for three values of the dye's levelling.



5

Figure 2.3: Push-pull versus groove depth of dye-only stacks for different values of levelling, groove width, and refractive index of the dye. Lowest curve corresponds to  $L = 0.5$ .

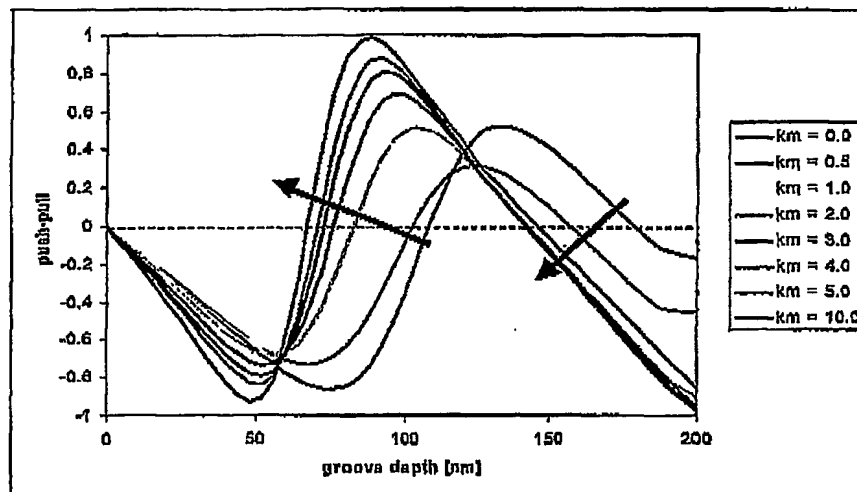
### 3. Groove-depth range for push-pull sign-inversion of an inverted optical recording stack as a function of the $k$ -value of the mirror

#### 3.1 Abstract

This is a generalization of Chapter 1. In chapter 1, groove-depth ranges were indicated for one specific wavelength  $\lambda$  (655 nm) and one specific mirror-type (Ag). Here we generalize the concept to arbitrary wavelength and arbitrary mirror. The mirror can be characterized by one parameter only, it's  $k$ -value (the imaginary part of the complex refractive index). The required groove-depth range for sign-inversion of the push-pull of an inverted stack is given by a simple formula. This formula is valid both for dielectric and metallic mirrors. The inverted stacks considered here may occur in DVR-R and in L1 of DVD+R-DL and in L0 of DVD+R-DL. The motivation for an inversion of the sign of the push-pull in such cases is given by compatibility with present read only optical disks .

#### 3.2 Considerations

We start by presenting some results obtained for DVD-conditions ( $\lambda = 655$



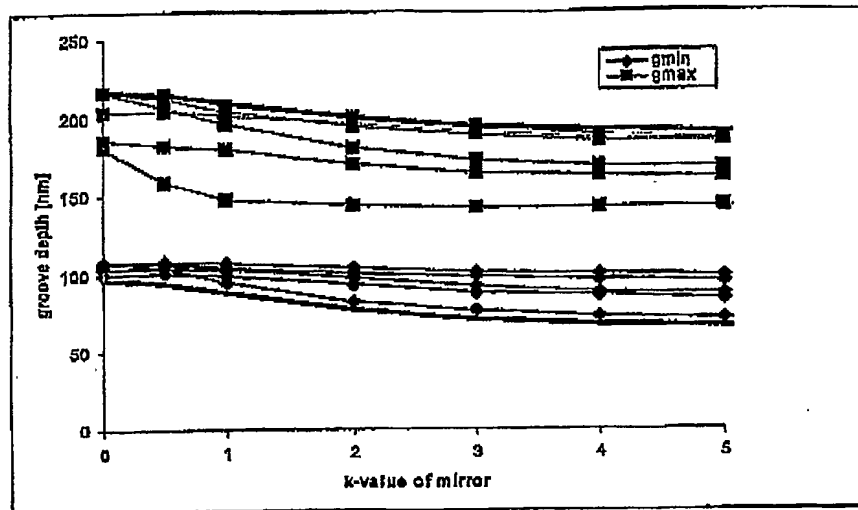
nm), later the results are generalized to arbitrary  $\lambda$ .

Figure 3.1: Push-pull for 75 nm dye ( $n = 2.5$ ,  $k = 0.05i$ ), 110 nm mirror ( $n = 1.4$ ) as a function of groove depth for several  $k_m$ -values of the mirror ( $\lambda = 655$  nm, 40% levelling of dye). The arrows indicate the effect of increasing  $k_m$  ( $k_m = k$  of metal).

Fig 3.1 shows the push-pull versus groove depth; with increasing  $k$  the range where the PP-amplitude  $> 0$  shifts to the left.

In Fig 3.2 are shown the minimum and maximum value of groove depth for which the push-pull is inverted ( $> 0$ ) for a number of stack-designs as a function of the

mirror's k-value. The groove-depths for which PP-inversion is achieved fall within a well-defined range which is bounded by the upper and lower (bold) lines.

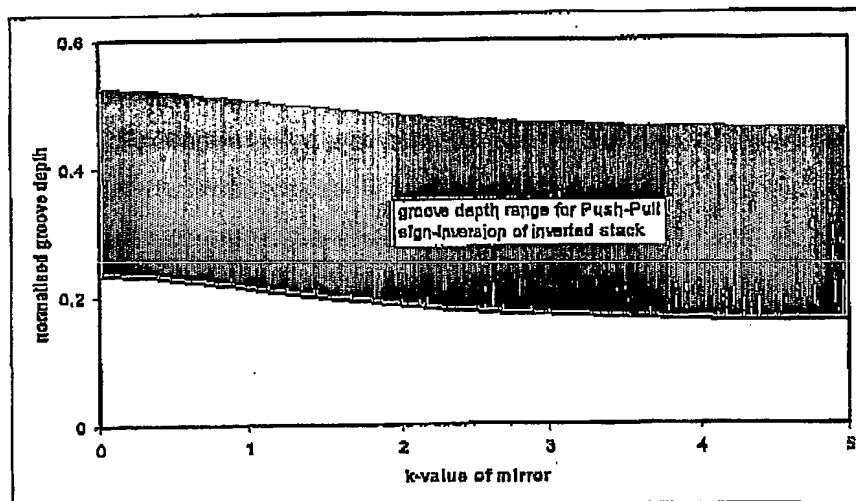


5 Figure 3.2: Minimum and maximum groove depth for which PP sign-inversion is achieved as a function of the k-value of the mirror.

### 3.3 Proposal

The next step is to generalize the above result, and this is shown in Fig 3.3 below. The groove depth is normalized to  $\lambda/n_0$ , where  $\lambda$  is the laser's wavelength and  $n_0$  is the refractive index of the substrate/cover/spacer/... covering the stack on the side from which

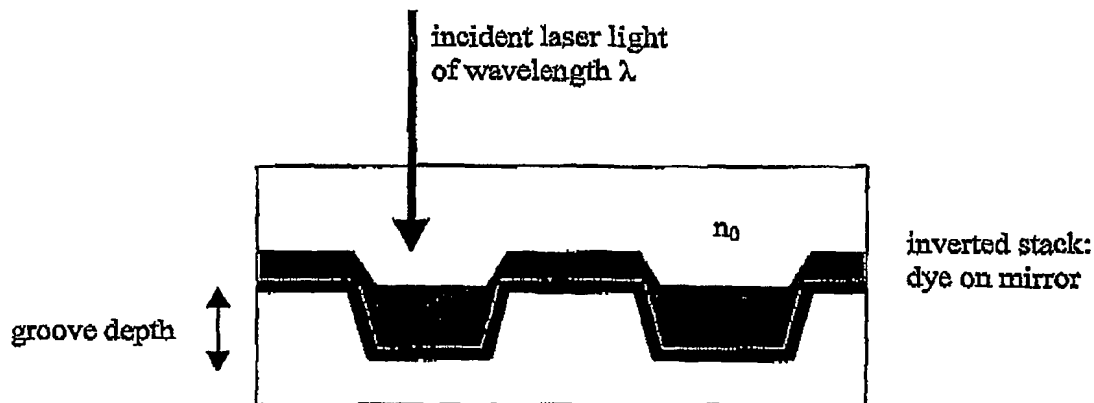
10



the laser is incident on the stack, see Fig 3.4.



Figure 3.3: Groove depth range for sign-inversion of the push-pull of an inverted stack as a function of the k-value of the mirror.



5 Figure 3.4: Inverted recording stack with organic dye-layer and mirror.

The groove-depth range shown in Fig 3.3 is mathematically described by:

$$0.25/(3.0 + k^2) + 0.15 < g \cdot n_0 / \lambda < 0.22/(3.0 + k^2) + 0.45$$

10

Note that the calculations have been performed for a levelling-range of 0.2 to 0.4 (higher levelling is unlikely, and when levelling = 0 there is no more need for in-groove recording).

### 3.4 Application

15 The present idea is applicable in case of any inverted recording stack where in-groove recording is required in an on-groove tracking drive (e.g. DVD+R-DL either L0, L1, or both and DVR-R). The stack contains a spin-coated layer.

20 The range defined above is independent of the stack's structure: dye-thickness, dye-levelling, etc. is not taken into account. Thus, the present formula can be seen as the most general case. More precise definition of a groove-depth range can be made for specific stack designs (e.g. dye-layer on Ag-mirror as was done in chapter 1)

In case of a multi-layer stack, what is the mirror (what k-value should be used in the formula)?

25 in the presence of metallic layers (thin or thick does not matter much) the high k-value of the metal dominates the stack's reflective properties and thus the groove-depth should be tuned according to the metal's high-k.

in the absence of any metallic layer, i.e. dye on a dielectric the mirror's  $k$ -value is simply equal to 0

in the case of a dye-only stack (unlikely-case) the substrate or spacer layer carrying the stack serves as dielectric mirror, i.e. again  $k = 0$ .

## CLAIMS:

1. An optical storage medium for for reading and recording information by means of a focused radiation beam having a wavelength  $\lambda$ , said medium comprising:

-a substrate, having a complex refractive index  $\tilde{n}_{S\lambda} = n_{S\lambda} - i*k_{S\lambda}$  at the wavelength  $\lambda$ ,  $n_R$  denoting the real part and  $k_S$  denoting the imaginary part of  $\tilde{n}_{S\lambda}$  including a guide groove with a depth  $g$ , an average width  $w$  and a trackpitch  $p$  and  $w$  in the range of 0.2 to 0.8 times  $p$ ; and

-a stack of layers on the substrate, which stack includes:

-a recording layer of a material having a complex refractive index  $\tilde{n}_{R\lambda} = n_{R\lambda} - i*k_{R\lambda}$  and having a thickness  $d_{RG}$  in the groove portion and a thickness  $d_{RL}$  in the portion between grooves; and

-a reflective layer of a material having a complex refractive index  $\tilde{n}_{M\lambda} = n_{M\lambda} - i*k_{M\lambda}$  and being present between the substrate and the recording layer; characterized in that

the following requirements are fulfilled:

$0.25/(3.0 + k_{M\lambda}^2) + 0.15 < g*n_S/\lambda < 0.22/(3.0 + k_{M\lambda}^2) + 0.45$  and  $0.2 < (d_{RG} - d_{RL})/g < 0.5$  and  $0 < d_{RG} < \lambda/n_{R\lambda}$  and  $k_{R\lambda} < 0.5$  and  $0 < k_{M\lambda} < 10$ .

2. An optical storage medium for reading and recording information by means of a focused radiation beam having a wavelength  $\lambda$ , said medium comprising:

-a substrate, including a guide groove with a depth  $g$ , an average width  $w$  and a trackpitch  $p$  and  $w$  in the range of 0.2 to 0.8 times  $p$ ; and

-a stack of layers on the substrate, which stack includes:

-a recording layer of a material having a complex refractive index  $\tilde{n}_{R\lambda} = n_{R\lambda} - i*k_{R\lambda}$  and  $k_{R\lambda} < 0.5$  and having a thickness  $d_{RG}$  in the groove portion and a thickness  $d_{RL}$  in the portion between grooves; and

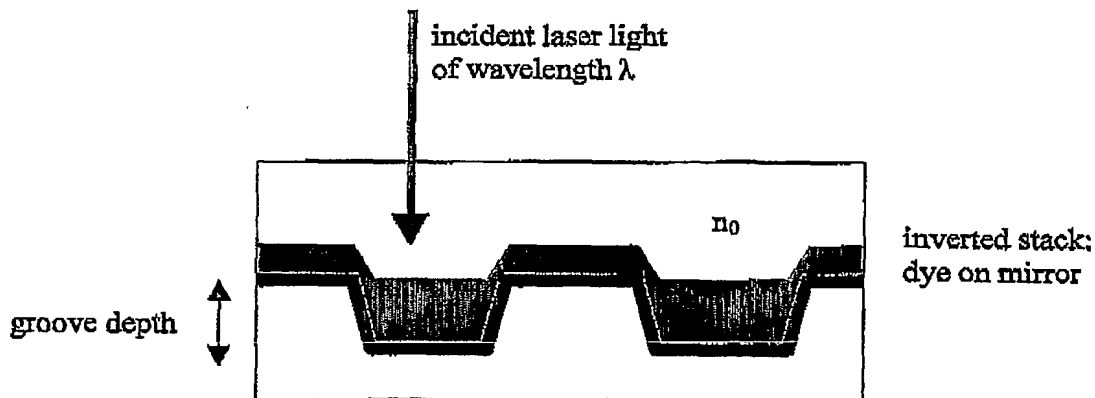
-a reflective layer of a dielectric material and being present proximate the recording layer; characterized in that the groove depth  $g < 125$  nm.

## ABSTRACT:

A recordable optical storage medium is described which has a guide groove and an inverted recording stack, comprising e.g. a dye. This reversed recording stack requires a reversed sign of the push-pull tracking signal. By using a specific range of parameters of the guide groove of the medium this push-pull sign reversal is achieved. The groove depth, normalized to the recording wavelength  $\lambda$ , is the most important parameter. In such a way the reversed recording stack of the medium is compatible with an optical drive employing standard push-pull guide groove tracking.

Further an optical storage medium is described which has a recording stack, including an organic recording layer, a dielectric reflective layer and a guide groove. When the guide groove depth is smaller than 125 nm the push-pull signal is sufficiently large to be compatible with the existing DVD standard for read only disks.

Fig. 3.4



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